ACCIDENTAL DETONATIONS IN UNDERGROUND MUNITIONS STORAGE MAGAZINES: PREDICTION OF COVER RUPTURE OVERPRESSURES

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INTRODUCTION

The Shallow Underground Tunnel/Chamber Explosion Test provides the only known airblast overpressure data produced by venting of the overburden cover from a decoupled high explosive detonation in a large-scale underground munitions storage chamber. A limited amount of overpressure data are available from fully-coupled underground high explosive detonations in alluvium (Buckboard 11 and 12, Stagecoach II and III, and Scooter events (Snell et al, 1971)), two recent tests in a recompacted soil media (Midnight Hour I and II), and small-scale Norwegian model tests in sand (Jenssen, 1979). This paper describes procedures used to develop prediction curves for overpressures produced by airblast venting through the rupture of the cover rock over an accidental explosion in an underground magazine.

TUNNEL/CHAMBER VENT PRESSURE

Hopkinson scaling is typically used when airblast overpressures from different explosives quantities are compared. Scaled distances are calculated by dividing the measured distance by the cube root of the explosive charge weight. A comparison of peak overpressures from the Shallow Underground Tunnel/Chamber Explosion Test (Joachim, 1990) and the NOL spherical surface burst curve (Swisdak, 1975) is shown in Figure 1. The peak data from the Tunnel/Chamber test decrease as a function of azimuth from the extended access tunnel centerline. The higher peak pressures, along the 0-degree azimuth, are the result of the jetting through the access tunnel portal.

A pressure-time history from a measurement point along the 180-degree azimuth gage line (Gage A-29) is presented in Figure 2 (Halsey et al, 1989). This gage was located on the ground surface 50 m behind the tunnel portal and 7 m behind a vertical projection of the rear wall of the explosives storage chamber. The wave form combines pressures expelled through the access tunnel portal as well as pressures vented through the ruptured overburden above the chamber. As shown in Figure 2, the airblast shock wave vented through the access tunnel

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portal arrived at this gage position 165 msec after detonation. The blast pressure wave vented through the overburden arrives 100 msec later at this gage station.

Peak pressures were from the overburden venting obtained by estimating the difference between the peak shown in Figure 2 and the exponentially decaying waveform from the early arriving pressure from the tunnel portal. In Figure 3, the estimated peak vent pressures are plotted versus horizontal distance from the source (i.e., horizontal distance from the gage to the vertical projection of the nearest chamber boundary). As shown in Figure 3, the peak vent pressure at the closest gage (7 m from the vertical projection of the rear wall of the chamber) is less than the airblast level that defines the Inhabited Building Distance (5.0 kPa).

COUPLING FACTOR

The DOD Explosives Safety Standards (1984) gives the following relation for computing the Inhabited Building Distance for ground motion effects:

$$D_{ig} = C\ f_g\ W^{4/9} \tag{1}$$

where D_{ig} is the Inhabited Building Distance, ft
C is constant for a particular earth material type
W is the weight of the explosives in the storage chamber, pounds.
and f_g is the decoupling factor, where

$$f_g = (4/15)\ w^{0.3} \tag{2}$$

where w is the chamber explosive loading density, pounds per ft^3. Since we are using Hopkinson scaling (cube root), some manipulation of the decoupling factor is required. Assuming that the equivalent charge weight is

$$W_e = f_g\ W^{4/9} = f_c\ W^{1/3} \tag{3}$$

where f_c is the equivalent decoupling factor for Hopkinson scaling, in metric units. After some algebraic manipulation, we find that

$$f_c = f_g^{3/4} \tag{4}$$

so $$f_c = 0.2\ q^{9/40} \tag{5}$$

where q is the chamber loading density, kg/m^3. The decoupling factor for a loading density of 66.4 kg/m^3 (used on the Shallow Underground Tunnel/Chamber Explosion Test) is 0.514.

VENT PRESSURE DATA

A comparison of the NOL curve for blast pressure from spherical-surface burst charges, vented pressure data from fully-coupled detonations in desert alluvium, and the decoupled Tunnel/Chamber test are presented in Figure 4. As shown here, the overpressure curve from the cover venting of the Tunnel/Chamber test plots in the vicinity of the Buckboard 12 and Scooter data for buried charges in alluvium. The minimum cover depth for the Tunnel/Chamber test was 9.4 m, giving a minimum scaled cover depth of 0.335 $m/kg^{1/3}$, compared with the 0.495 and 0.496 $m/kg^{1/3}$ depths of burst for the fully coupled events in alluvium. The scaled charge radius of a spherical TNT charge is approximately 0.053 $m/kg^{1/3}$. Thus, a 0.495 $m/kg^{1/3}$ depth of burst provides approximately 0.44 $m/kg^{1/3}$ overburden depth above the buried charges. The comparison presented in Figure 4 shows reasonably consistent agreement for the variations in cover depth (or equivalent depth of burst) considering that two very different media were involved--weathered granite and desert alluviumfor the fully-coupled events.

A similar comparison of vented overpressures is shown in Figure 5 between the NOL curve, small-scale Norwegian model tests in sand, and the Tunnel/Chamber decoupled detonation. As shown here, vented pressures from the small-scale charges at a depth of burst of 0.50 $kg/m^{1/3}$ (cover depth approximately 0.44 $m/kg^{1/3}$) are an order of magnitude less than those measured from the decoupled Tunnel/Chamber detonation. Thus, the small-scale tests in sand do not model large decoupled detonations in granite.

Lines of estimated fit were drawn through the data for fully-coupled, buried charges in alluvium in Figure 4 to provide a means of estimating scaled horizontal distances to the vented overpressure levels of interest (ranging from 50 to 240 mb). Least square fits were calculated for the Midnight I and II, and

the Stagecoach II and III data, with the results used to estimate curve fits for the remaining data. The resulting data fits are shown in Figure 6.

The curves for peak vent pressure versus scaled distance developed in Figure 6 were used to obtain the overpressure contours presented in Figure 7. As shown here, the scaled horizontal distance to the 50-mb contour (airblast criterion for Inhabited Building Distance) decreases rapidly as the scaled overburden depth is increased from 0 to 0.15 m\kg$^{1/3}$. The scaled horizontal distance to the 50-mb overpressure contour for a cover depth of 0.15 m/kg$^{1/3}$ is 10 m/kg$^{1/3}$.

DISCUSSION

The use of the vented overpressure curves in Figure 7 are best illustrated with a few examples. Assume that a chamber is loaded with 113,500 kg (250,000 lb) of explosives at a loading density of 100 kg/m^3. The coupling factor for this loading density is 0.564. The equivalent coupled charge is computed to be 0.564 x 113,500 kg - 64,000 kg. The cube root of the 64,000-kg explosive weight in the chamber is 40 kg$^{1/3}$. The 50-mb vented overpressure occurs at a horizontal distance of 0.4 m/kg$^{1/3}$ (16 m) for a cover depth of 0.44 m/kg$^{1/3}$ or 17.6 m, as compared to the K19 distance of 365 m computed in the current Standards. Next, consider the same total explosive weight (113,000 kg) and chamber loading density (100 kg/m^3), but with a scaled overburden depth of 0.14 m/kg$^{1/3}$ (5.6 m). The airblast Inhabited Building Distance (50 mb) is 404 m, compared with the same K19 distance (364 m) for this explosive quantity. Thus, the airblast Inhabited Building Distance to the rear of an underground magazine (180-degree azimuth) specified by the current Standards is greater than hazard distance actually produced by cover venting, when the scaled cover is relatively thick. Additional analysis is required however, to determine the level of overpressure venting through the overburden when the scaled cover thickness is less than 0.2 m/kg$^{1/3}$ for this explosive quantity and chamber loading density.

Based on an airblast criterion of 50 mb, the Inhabited Building Distance for overpressure from overburden venting (Figure 7) on the Shallow Underground Tunnel/Chamber Explosion Test (22,000 kg, (TNT equivalent), with a chamber loading density of 66.4 kg/m^3, and a scaled cover depth of 0.34 m/$^{1/3}$, is 32.7 m. The airblast gage at a horizontal distance of 7 m from the back wall of the

chamber recorded an estimated vent pressure of 40 mb. Thus, the vented airblast pressure contours shown in Figure 7 are conservative.

CONCLUSIONS

The overpressure prediction curves developed in this analysis (Figure 7) indicate that a scaled cover depth of 0.5 $m/kg^{1/3}$ is sufficient to contain all hazardous airblast overpressure (greater than 50 mb) vented through the ruptured chamber overburden. The analyes also indicate that the 50-mb pressure criterion for Inhabited Building Distance will occur at a horizontal distance of 0.4 $m/kg^{1/3}$ for typical underground magazine explosive quantities. This restricts the hazardous overpressure distance from cover venting to the immediate vicinity of the storage chamber. Therefore, it is suggested that the maximum scaled depth of overburden (C_c) specified in DOD 6055.9-STD (SEction G.4.d.2) for which overpressure venting must be considered should be changed to a value consistent with the NATO hazard criteria for ejecta/debris, namely $C_c = 0.8$ $m/kg^{1/3}$ for hard rock and $C_c = 1.0$ $m/kg^{1/3}$ for soft rock. The data presented in Figure 3 indicates that these values would be conservative as far as hazardous venting overpressures from rupture of the chamber cover are concerned.

As the scaled cover depth decreases from 0.2 $m/kg^{1/3}$, the scaled horizontal distance to the 50-mb overpressure level increases at a slower rate for all the cover venting overpressure curves plotted in Figure 7. The vented overpressures from chamber cover rupture are approximately one-tenth of the overpressures predicted by surface detonations of the same yield; at this scaled cover depth the vented pressures will increase rapidly, however, as the scaled cover depth decreases. Therefore, the value of 0.2 $m/kg^{1/3}$ for the minimum scaled cover depth given in the present Standards appears reasonable.

RECOMMENDATIONS

A series of decoupled buried explosive tests is needed to more accurately define the venting pressures and explosive energy equivalence for detonations in shallow underground magazines.

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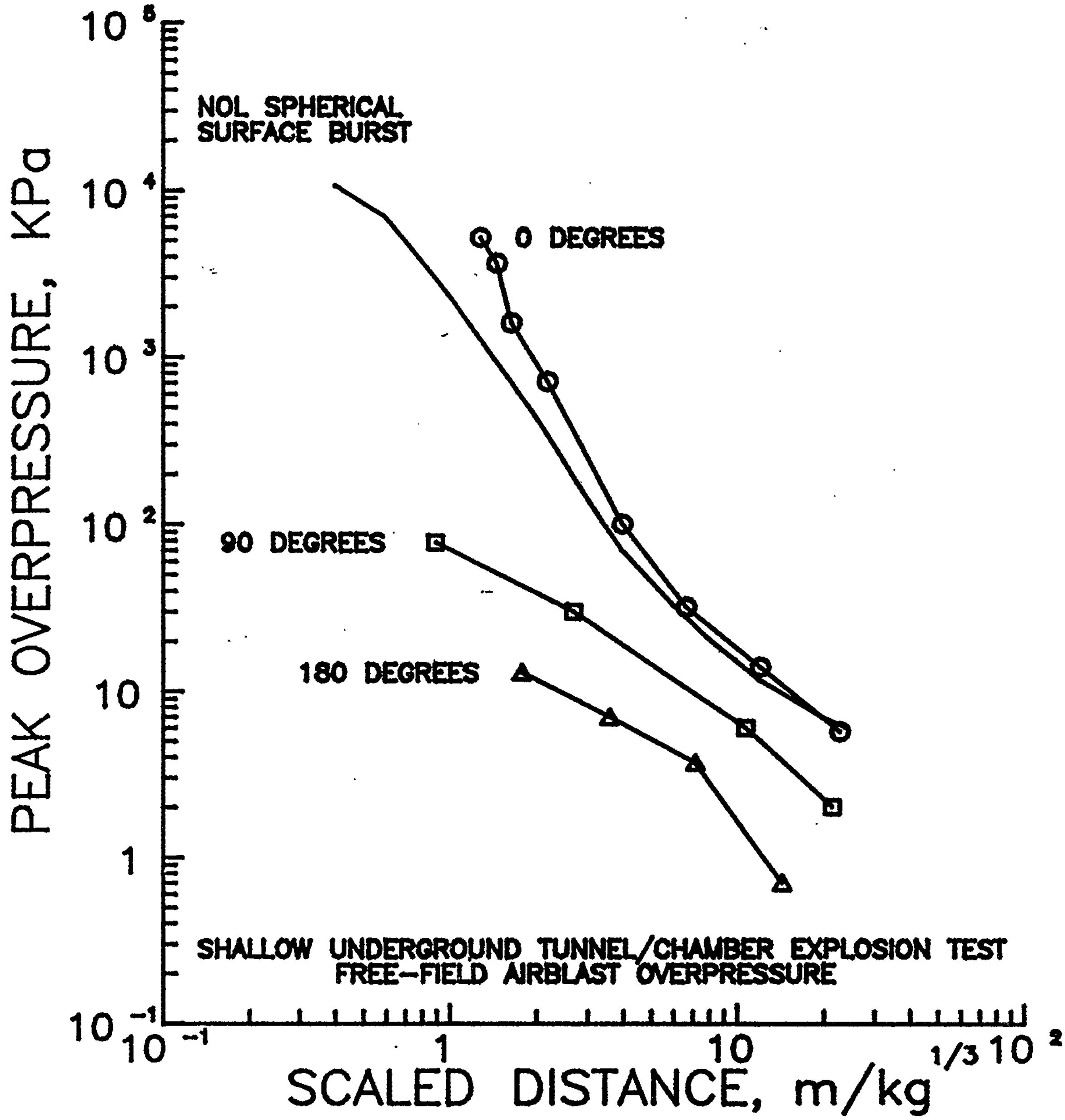

Figure 1. Comparison of free-field airblast overpressures from NOL spherical surface burst calculation and the Shallow Underground Tunnel/Chamber Explosion Test (0, 90 and 180-degree azimuths).

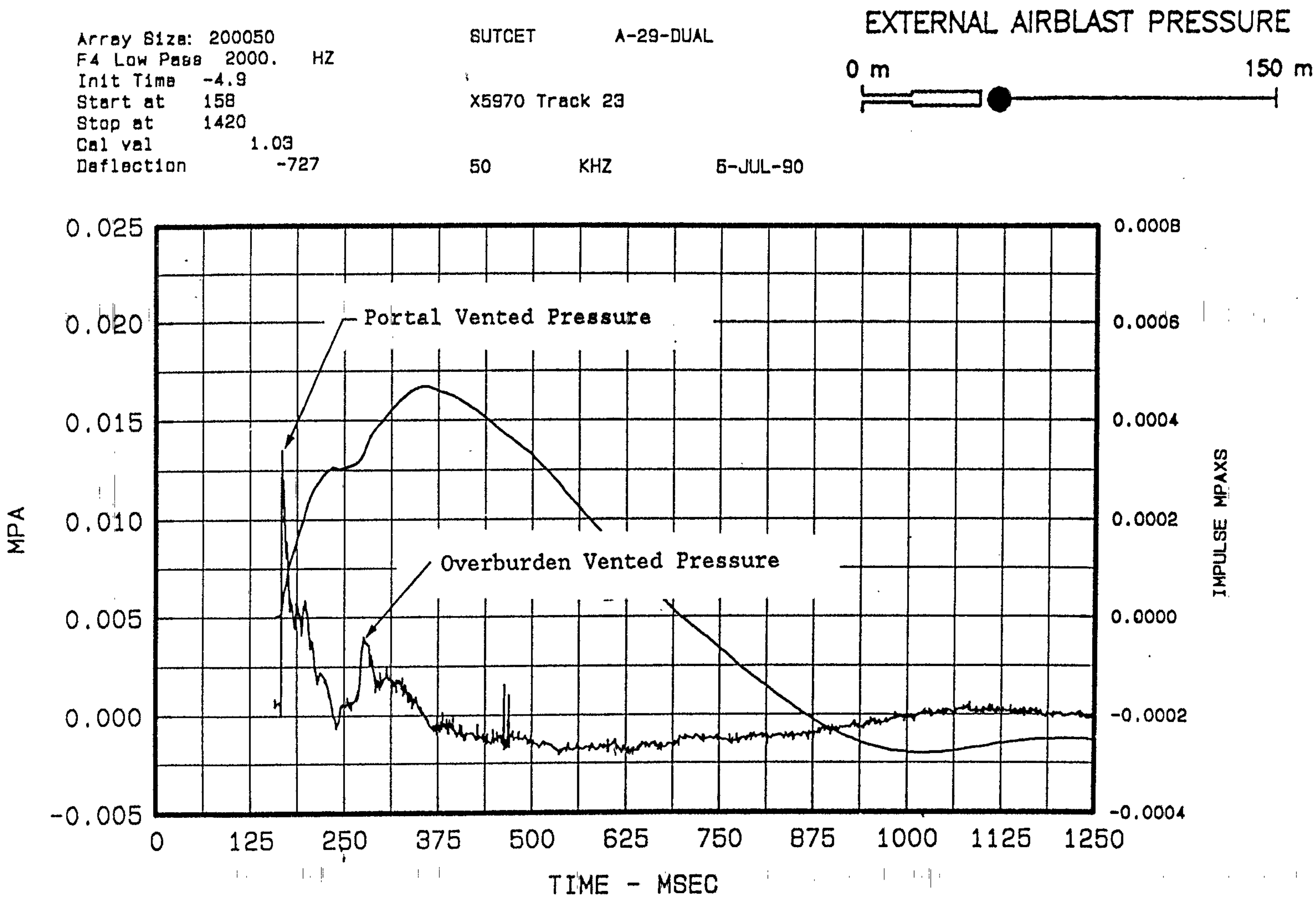

Figure 2. Portal and overburden airblast overpressure and impulse wave forms at Gage A-29, from decoupled detonation (Shallow Underground Tunnel/Chamber Explosion Test). Gage is located along 180-degree azimuth, 50 m from access tunnel portal (7 m from vertical projection of nearest chamber wall).

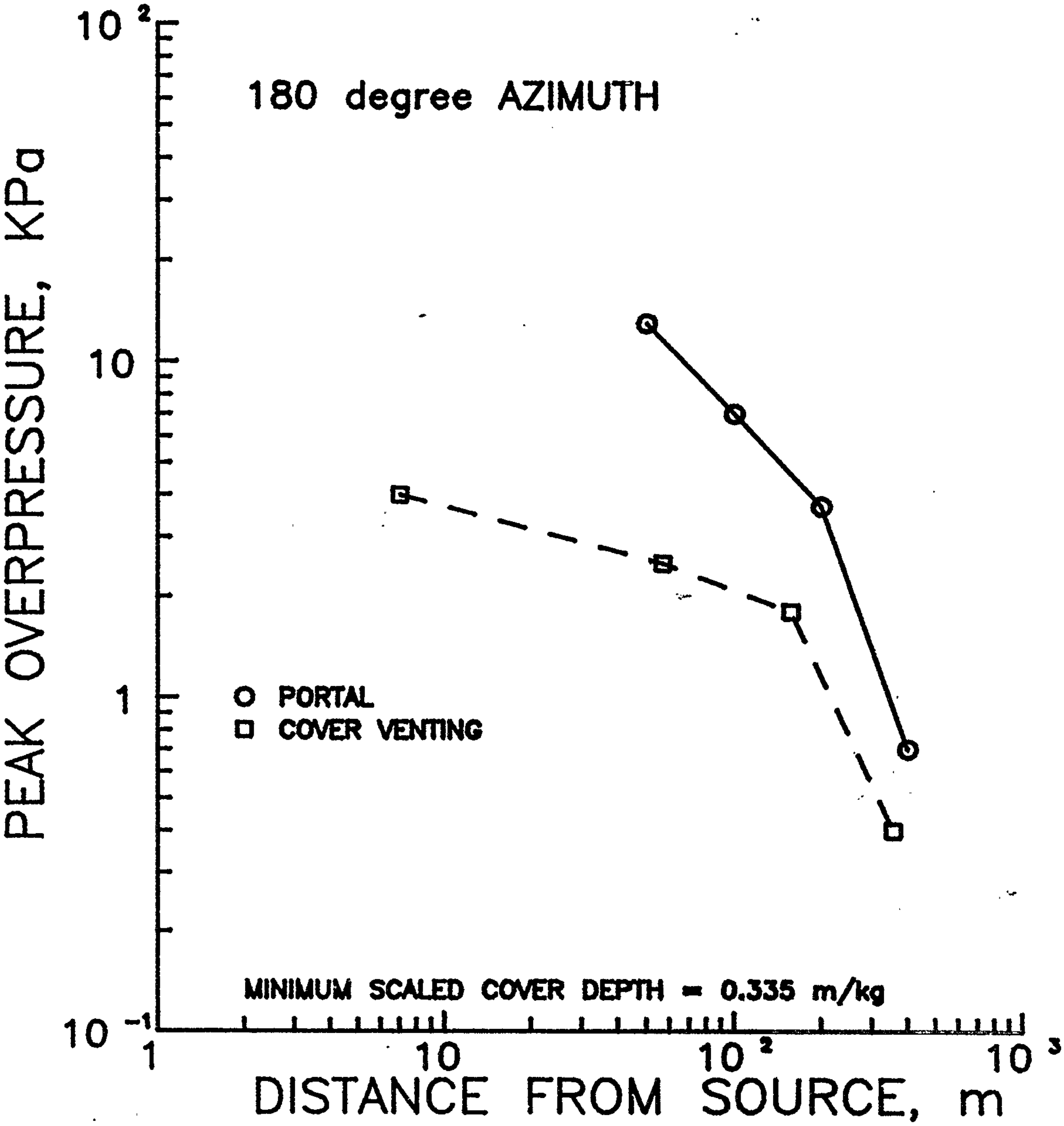

Figure 3. Comparison of portal and overburden vented overpressures along the 180 degree azimuth, Shallow Underground Tunnel/Chamber Explosion Test.

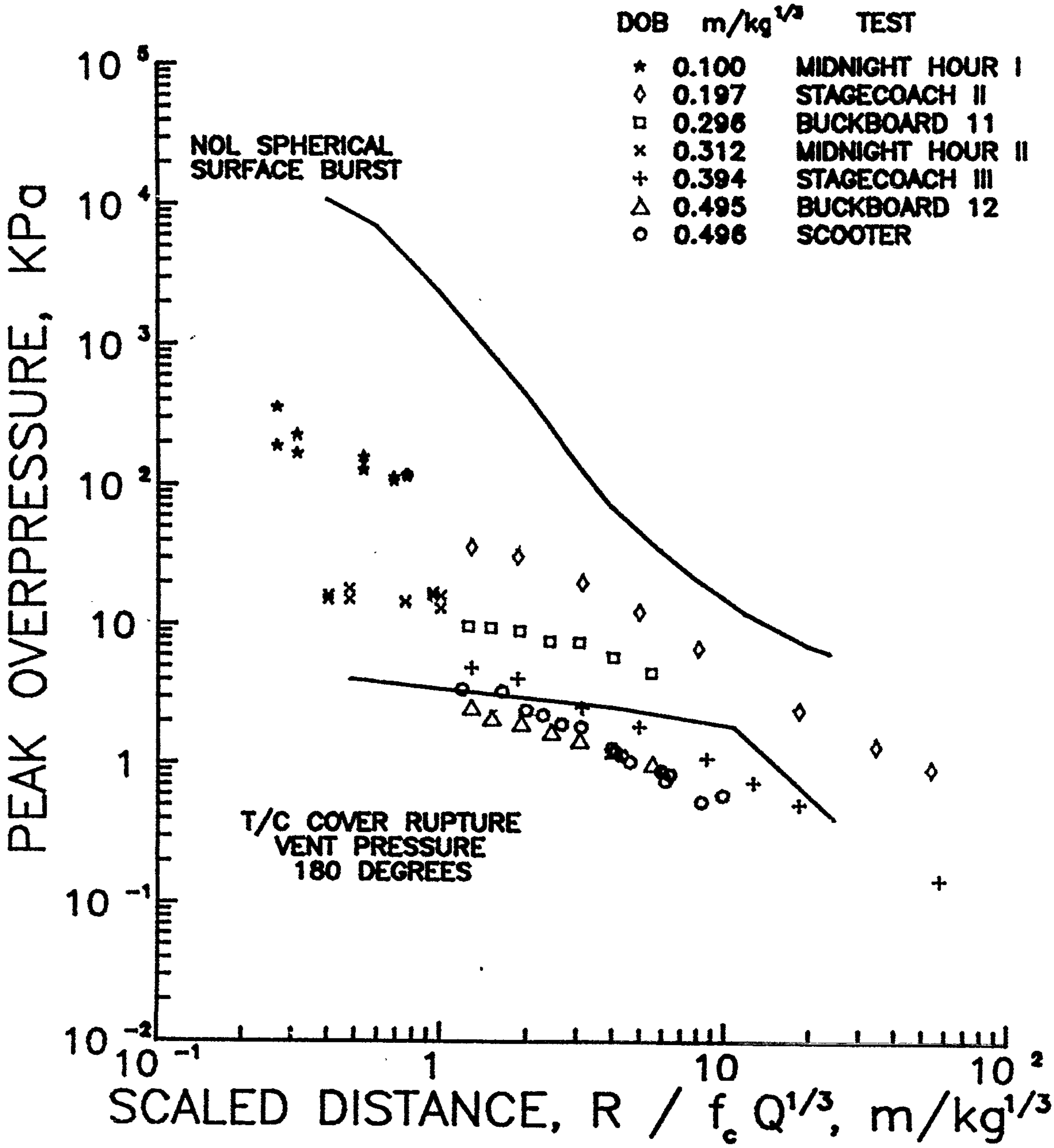

Figure 4. Comparison of vented airblast overpressure data from fully-coupled, buried detonations in desert alluvium with the NOL calculated pressure for spherical surface bursts and measured vent pressures from the decoupled Tunnel/Chamber test.

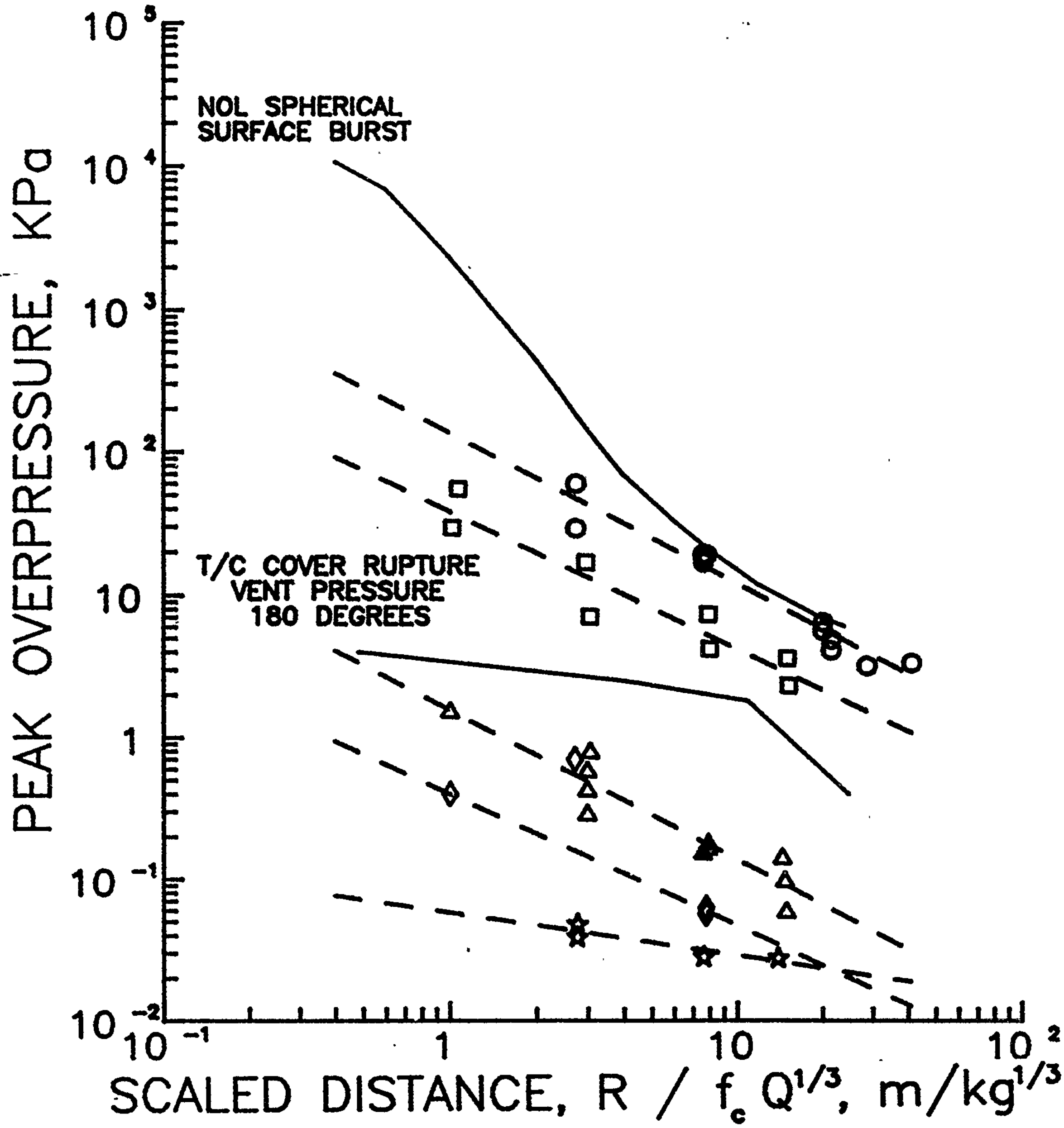

Figure 5. Comparison of vented airblast overpressure data from fully-coupled, buried small-scale detonations in sand (Jenssen, 1979) with the NOL calculated pressure for spherical surface bursts and measured vent pressures from the decoupled Tunnel/Chamber test.

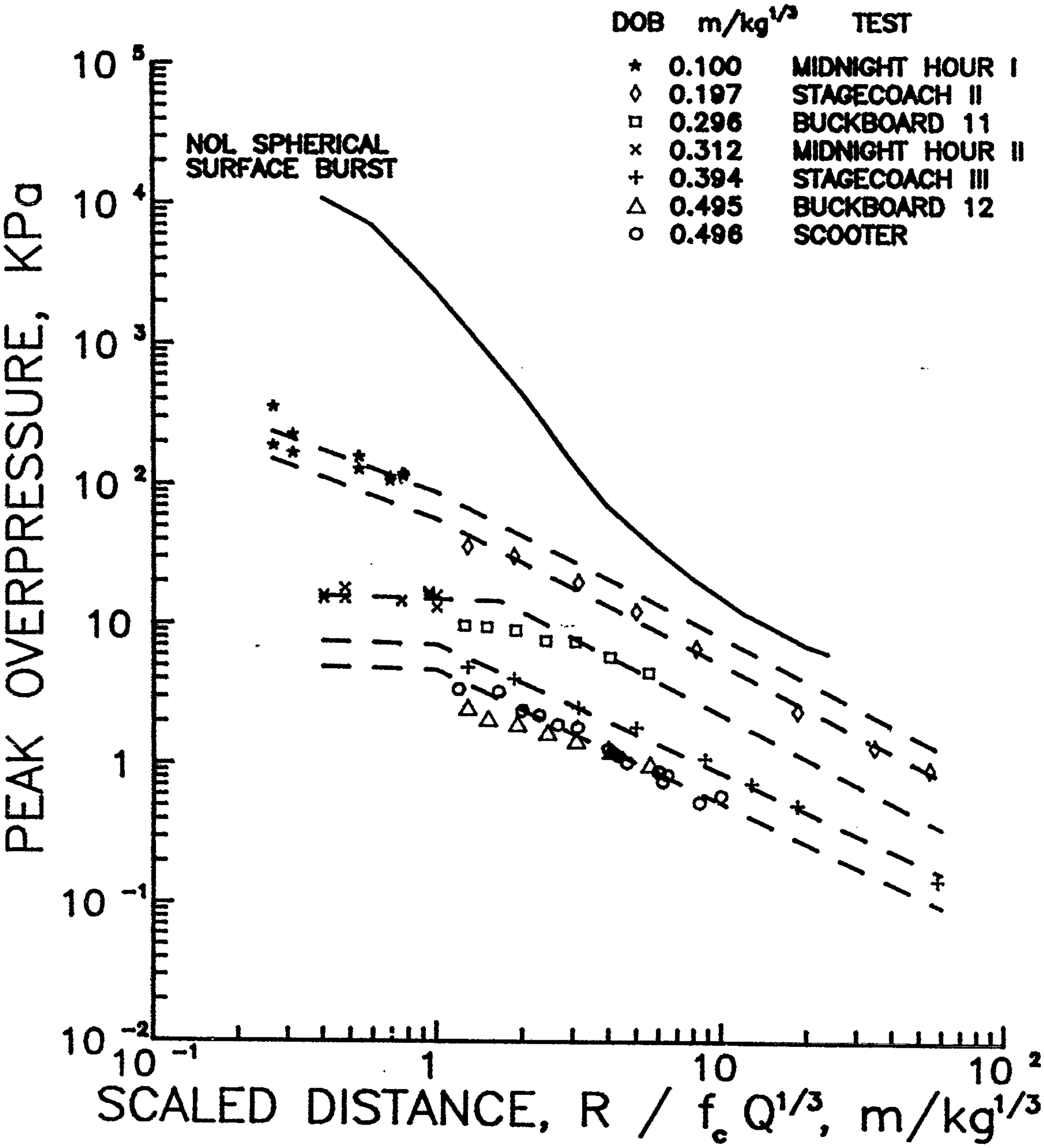

Figure 6. Peak pressure versus scaled horizontal distance for fully-coupled, buried detonations in desert alluvium, with estimated best-fit curves.

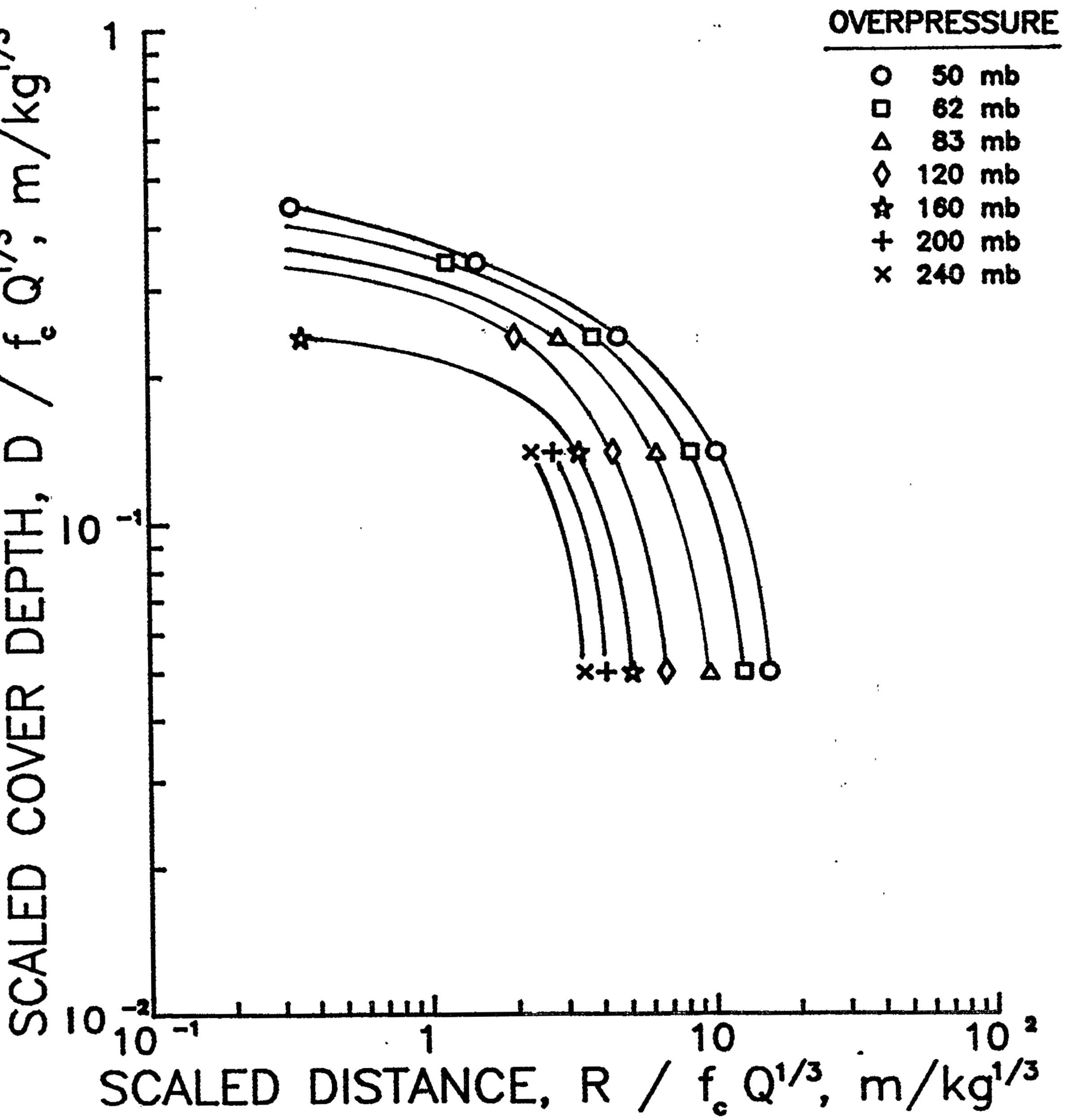

Figure 7. Airblast overpressure contours as a function of scaled cover depth and scaled horizontal distance from detonations in underground munitions storage chambers.